Literature Review:
The environmental impact of polyacrylamides applied to soil and water

by Shane Phillips,
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Introduction to Polyacrylamides

Organic polymers such as polyacrylamide (PAM) and polyvinyl alcohol (PVA) have been used to stablise soils, control erosion and to increase water and nutrient infiltration and retention. Considerable success in using organic polymers has been demonstrated by Williams *et al* (1967), who showed that soil aggregate stability in water was greatly increased in soils treated with PVA. Finch (1973) writes on the use of PVA as a soil conditioner. PVA applications to soil help to improve soil structure by converting soils of single grained structure to a crumbed form. Wallace *et al*. (1986) describe how polymers created 100% water stable aggregates compared with only 38% in the control. Aase et al (1998) also writes on how PAM reduced runoff and erosion in sprinkler irrigated laboratory tests. These are just some examples of how polymers can have a role in soil and water conservation.

The basis for the utility of organic polymers is their long chain molecular structure which contain repeating units held together by strong covalent bonds (Young 1981). There is almost an infinite number of molecular formulations, and each one has physical and chemical properties that vary to different extents. As might be expected therefore, some polymers are more suitable than other for stabilising different types of soil. . PAM for example, is a water soluble polymer used largely for thickening and floculation whereas Polyacrylonitrile is only slightly water soluble (Billmeyer 1971). Finch (1973) found that PVA is effective for use in loam soils with a high clay content, but not as effective with volcanic ash soils.

Polymers can be seen to adsorb readily onto solid surfaces. Each polymer group or polymeric ion can have many groups or segments that can be potentially adsorbed, the groups being essentially free of mutual interaction (Stumm 1992). The extent of adsorption can be seen to generally increase with an increasing polymer molecular weight. The number and type of functional groups within the polymer molecule also affect the extent of adsorption (Stumm 1992).

The widespread agricultural use of polymers over the past 40 years may have been restricted by cost and application rates. Finch (1973) outlines amounts of PVA required per 100 metres square of field area. Rates up to 8-10 kg PVA/100m2 are quoted for clay soils with a content of soil grain particles less than 0.01mm diameter (%). When coupled to the procedure outlined on applying the product it would make the correct application relatively difficult. Nevertheless, there is considerable scope for the use of organic polymers in horticultural ventures where the costs are more easily justified. Furthermore the most effective rate for a polymer application will probably differ not only for the soil type but also the chemistry of the irrigation water. The likelihood of an economic formulation may increase considerably in cases where the need for industrial refinement is minimised or where organic polymers are produced as waste from other processes. Seybold (1993) writes that work in the 1970's on the use of polymers as soil conditioners while effective was not cost efficient.

Of particular interest to this study is the potential use of various synthetic organic polymers known as polyacrylamides (PAM). These have many practical applications, including their use in municipal water clarification, flooding agents for petroleum recovery, soil stabilisation, paper thickening and strengthening agents. Finch (1973) outlines the various applications of PVA. Seybold (1993) documents a historical use of polymers in particular the polyacrylamide group. PAMs were originally used in World War II to allow rapid construction of roads and runways under adverse conditions (Wilson, 1975). The development of PAM technology after WWII found its way into the USA agricultural industries in the 1950's for example, to enhance the stability of tilled agricultural soils (Azzam, 1980), and as a coating agent in the formulations of biopesticides (Burgess, 1998). It is estimated that approximately half a million hectares of irrigated farmland in the USA currently use PAM for erosion control, infiltration enhancement and improvement of runoff-water quality (Sojka, 1999). This particulary in relation to the loadings of nutrients, pesticides, micro-organisms, weed seeds (and thus biological oxygen demand) in water bodies that receive runoff.

An understanding of the physical and chemical properties of PAM is crucial in deciding how best to make use of them in any given situation. The following literature review looks at polyacrylamides and environmental fate following their application to both soil and water.

Polyacrylamide (PAM)

PAMs are syntheised in four main structural groups, cationic, neutral, amphoteric and anionic (Seybold, 1993). The anionic groups are most commonly manufactured as the others can be environmentally toxic (Sojka, 2000). For example, some cationic PAMs have been shown to LC50s rates low enough for concern with aquatic organisms.

The formulation of the PAM can vary according to polymer chain length and the number and kinds of functional group substitutions along the chain. The PAM amide group can be replaced with functional groups containing sodium ions or protons that dissociate in water to provide negatively charged sites (Sojka & Lentz, 1999).

PAM is formulated from the carboxylic group, 2-propenoic acid (acrylic acid). Acrylic acid provides the anionic charge while the acrylamide monomer provides the 'backbone' of the polymer. Because the carboxyl group contains three polar covalent bonds, carboxylic acids are polar compounds. They are capable of interacting with water molecules by hydrogen bonding through both the carboxyl oxygen and hydroxyl group. The carboxyl group consists of of two distinct parts, the hydrophilic carboxyl group and a non polar hydrophobic hydrocarbon chain. The hydrophilic carboxyl group increases water solubility and the hydrophobic hydrocarbon chain decreases water solubility. As the size of the hydrocarbon chain increases relative to the size of the hydrophilic carrier water solubility decreases (Brown, 1988). This explains the difficulty with dissolving high molecular weight PAM.

Properties of aqueous polymer solutions and adsorption of PAM

While this study is concentrating on the polyacrylamide group it is worth noting the first synthetic polymer and its application over a wide range of industry. PVA was the first totally synthetic colloid, being prepared from polyvinyl esters in 1924 (Finch 1973). PVA was prepared by polymerising vinyl acetate. PVA is not the monomer but a polymerised ester (Finch 1973). When pure, it is a white hydrophilic powdery solid that is flammable and explosive. PVA has an ability to absorb water. The amount of water adsorbed per unit volume of PVA is proportional to the external vapour pressure of water up to 50% relative humidity. The coefficient of adsorption is equivalent to about 13 moles of water per hundred moles of CH_2CHOH (Pritchard 1971).

PVA (and PAM) can be seen to dissolve more rapidly as the temperature is increased. As salinity levels increase the intrinsic viscosity of the aqueous PVA increases with increasing concentration of sodium hydroxide up to 6%. Once the concentration of sodium hydroxide exceeds 6% intrinsic viscosity (IV) solubility decreases strongly. It is assumed that the hydrogen bonding of water to PVA is seriously modified by sodium hydroxide and the polymer hydrogen bonds more to itself and gets effectively salted out of solution. The IV is also increased by the addition of urea to PVA solutions (Pritchard 1971).

As with many water soluble polymers, the degree of solubility of PVA depends upon the degree of polymerisation and degree of hydrolysis.

Emulsion polymerisation can be undertaken using solutions of hydrophilic monomers. Acrylic acid or acrylamide can be emulsified in a continuous oil phase using an appropriate water in oil emulsifier (Billmeyer, 1971). PAM as a water soluble polymer is very hydrophilic and as such is used as a thickening agent and floculant.

The viscosity of PAM can be seen to decrease with increasing flow rates for concentrations greater than 400ppm (Bjorneborg,1998). It was determined that it was difficult to accurately determine PAM viscosity because not only did viscosity vary with concentration and temperature but with flow conditions. It was determined that pumping PAM (2400ppm concentration) once through a centrifugal pump reduced viscosity 15-20%. The viscosity reduction being thought to result from breaking or shearing the PAM molecules reducing its effectiveness to stabilise the soil surface and reduce soil erosion. It is interesting comparing this work to drip irrigation. Most fertigation systems use diaphragm pumps that would less physically abrasive than a centrifugal pump. It is therefore worth considering that the pump used in field operations could well contribute to the effectiveness of the PAM on soil type and structure.

PAM, infiltration and soil erosion

Flood and or furrow irrigation is still a major main mean by which water is applied to irrigated crops in the world. In 1993 it was still the main method of irrigation in California, USA (Carter *et al*, 1993) In Australia furrow and flood irrigation dominate rice and cotton production. A consequence of flood /furrow irrigation is water runoff at the end of the row and erosion of suspended soil particles. Soil sediments lost in return flows along, with pesticides and nutrients absorbed on the sediment, are regarded as major contributors to non-point pollution of surface water (Sojka and Lentz, 1993). Ross *et al.* (1996) reported topsoil losses of 5- 50 tonnes per hectare per year on erodible soils in the USA Pacific Northwest. Some of the major impediments to changing irrigation practices from flood to pressurised systems have been the low cost of water, the high cost of developing pressurised systems and general resistance to change. As a result of these concerns the use of organic polymers to modify soil properties has been investigated (Azzam, 1980). The use of PAM has resulted in changes in reduced rates of soil erosion and increased water infiltration.

Sojka and Lentz (1994) documented the role that PAM soil application played in reducing irrigation-induced erosion. The most impressive results in erosion control were obtained with the use of high molecular weight PAM. Soil erosion was controlled with the application of 10mg/L PAM (18% anionic) in the advancing furrow stream. PAM was also seen to be more effective when applied with the irrigation water rather than added as dry blended product onto the soil. Sojka and Lentz (1994) documented how applications of PAM in furrow irrigation eliminated up to 94% of runoff. Increases in water infiltration of up to 50% at the furrow outlets were reported from the use of PAM in this system. Aggregate stability was increased from 54 to 80% in 1993 and 63 to 84% in 1994.

Trials conducted across Northern Australia from 1995 - 97 (Schiller, 1997, unpublished) investigated the role of PAM in reducing soil runoff and improving infiltration. This work revealed reductions in the advancement of water when treated with PAM at rates of 1.2, 2 and 3.6 ppm. Measurement of water infiltration using a neutron probe indicated that infiltration was improved on coarser soils, whereas on the heavier Darling Downs soils, very small infiltration increases were recorded. Sediment runoff and turbidity were reduced in tailwater (the water at the end of the furrow irrigation) with the use of PAM. Measured levels of sediment in tailwater decreased from 0.4 - 1.8 g/L in control areas to 0.1g/L –(undetectable) where 3.6 ppm PAM was applied per volume of irrigation water. Further studies of tailwater indicated that with the use of PAM, pesticide and herbicide levels could be reduced. In the case of Oxyfluorfen residues in tailwater, reductions of 100% were achieved through the use of PAM.

Ross *et al.* (1996) wrote on improvements in infiltration and reduced sediment runoff through the use of PAM. High molecular weight PAM were observed to reduce sediment runoff by 96% in furrow irrigated highly erodible Portneuf silt loam soils of Idaho. Net infiltration over the furrow length in a 12 hour period increased by an average of 10%. Studies in this trial revealed that uptake of acrylamide by the plant was undetectable. The results of this trial indicated that there was no adverse environmental effects or potential health risks if recommended procedures were followed.

Studies by Levy *et al.* (1991) showed that an inverse relationship exists between vegetative growth of cotton on the one hand and the level of runoff on a commercial field scale on the other. The use of PAM (at 20 kg/ha) was seen to significantly reduce runoff from both vertisol and loess soils. A trend was observed where treatment with PAM increased yields compared to the control. In modelled sprinkler irrigation systems (Levy *et al.*1992) the effects of 5, 10 and 20ppm concentrations of 2 PAM. These were applied during the first three consecutive irrigations, and thereafter the soils received two subsequent irrigations with water only. Both PAM treatments stabilised soil aggregates and increased their resistance to erosion. It was suggested that PAM is an effective agent in limiting runoff and erosion from soils sensitive to sealing and therefore could be beneficial in increasing yields.

Stern *et al.* (1992) documented runoff from sprinkler-irrigated wheat crops at 36% of total irrigation. When water was treated with PAM plus phosphogypsum, these had runoff of only 1.4% of total irrigation volume. Phosphogypsum treated water alone had runoff of 13% irrigation volume. The PAM treatments also gave significantly higher grain yields and greater crop water use efficiency than the control plots.

Trout *et al.* (1995) reported that 0.7 kg /ha of a high molecular weight PAM reduced furrow induced erosion by 85-99%. PAM was also seen to increase net infiltration by 30%. It was postulated that this was the result of reduced sediment movement and furrow surface sealing. Infiltration was also inversely related to the maximum sediment concentration in the flowing water. The Murray and Darling Rivers are regarded internationally as being high in colloidal material. Growers using PAM in drip irrigation systems have recorded increased infiltration and lateral spread of moisture via moisture monitoring equipment and observing changes to flow patterns as a result of increased flocculation of this colloidal material. The flocculating nature of PAM used in drip irrigation systems appears to remove colloidal material from within the drip line. This may therefore increase flows (increasing pipe size or friction losses). Alternatively as sediment is reduced in the water flow, infiltration and subsequent lateral spread of moisture is increased. The number of flushing valves in drip-irrigated enterprises highlights the amounts of impurities that still get past the primary filtration systems whether they be sand or disc filter systems.

Vallant (1997) describes how the use of PAM helped to reduce erosion and increase yields of furrow irrigated tomatoes and peppers. Soil loss was reduced by 63% and yield increases of 30% were recorded. Pryor (1988) also highlighted the role PAMs play in increasing the yield of processing tomatoes. Application of up to 15 kg/ha of a cross linked PAM resulted in yield increases of 30% when sidedressed into canning tomato beds. The paper further highlights the potential of PAM in drought prone or sandy soils, or where water is highly priced or in short supply. Sousa and Osterli (1998) used PAM at a concentration of 10 ppm to irrigate processing tomatoes. In one section PAM was used in the first 6 of 9 irrigations and in the other section a further PAM treatment was applied in the eighth irrigation. Yield increases at the 90% level of statistical significance were recorded. Results from this trial showed that treatment with PAM resulted in more water being available to the plant

Gardiner and Shainburg (1996) described how the use of PAM at 10, 25 and 40 ppm improved hydraulic conductivity of soils significantly. The effects being most apparent in the first few weeks then tapering off. This paper reported that the use of PAM had a greater impact on soil hydraulic conductivity than gypsum. PAM may also have a role in reducing wind drift. Chamberlain (1988) suggests that polymer treatment of the ground will stabilise soils against wind drift. In crops such as carrots and onions where wind damage at emergence can seriously reduce yields, polymers may play a stabilising role when applied after seeding.

Lentz *et al.* (1993) showed that PAM charge type or charge density had a major influence on furrow erosion. PAM was applied at 10ppm during the initial 30 minutes of irrigation. The nature of the charge on the PAM influenced the efficacy of erosion control. With anionic and cationic charge PAM efficacy was increased with increasing charge density. The effectiveness with respect to charge was anionic>neutral>cationic. The toxicity problem associated with cationic PAM seems to be combined with a reduced effectiveness at equivalent concentrations in solution.

Orts *et al.* (2000) used biopolymers to reduce shear induced erosion in laboratory studies. The use of biopolymers at rates up to 120ppm reduced suspended solids by more than 80%. The use of PAM reduced runoff by >90% at rates as low as 5ppm. This work indicated the effectiveness of PAM in reducing suspended solids in runoff at low application rates.

Many other studies have produced similar information with regards to reduction in irrigation induced soil erosion. Becker (1997) reports that PAM applied at 5-10 ppm almost completely eliminated rill erosion. Combining gypsum and soil applied PAM also improved infiltration and reduced soil erosion. The low operating costs of furrow irrigation make it a likely system to remain in place until either environmental or economic opportunities allow change to proceed. In these systems the use of PAM offers growers a solution to minimise issues involving irrigation induced soil erosion. In a world where economic and environmental issues are increasingly important the cost of using PAM in furrow based systems may offer irrigators a low cost option in reducing erosion and increasing water infiltration over installing pressurised systems.

Interms of nutrient retention in soil and reduced runoff polyacrylamides play a significant role in controlling potential pollution issues by controlling runoff from fields.

Impact of PAM applications on soil sodicity and structure.

Increasing salinity levels in water across the world is posing problems to not only rural but also to city dwellers. Declining water quality poses threats not only to agricultural production but also to urban roads, buildings and other infrastructure. As salinity levels increase, strategies will have to be developed that will enable irrigated agricultural production to be maintained or even increased with inputs (such as increasingly saline irrigation water) that will have a negative impact on crops. The use of PAM offers an interesting opportunity in the battle against salinisation. In the Murray Darling Basin of Australia increasing salinity is a major problem facing the rural community. The increasing extraction of water from the river system is raising real concern over potentially dramatic increases in long term river salinity levels.

Highly sodic water is used for irrigation in parts of the middle east. High sodium concentration water creates problems with long term infiltration, reduced hydraulic conductivity and surface crusting. Gardiner and Shainberg (1996) investigated the use of PAM and or gypsum to overcome the effects of sodium. Soil was exposed to PAM at 0,10,25 and 40 mg/L and then to weekly applications of wastewater over a period of eight weeks. In each soil an application of PAM resulted in hydraulic conductivity being improved significantly. In this experiment PAM performed better than gypsum in increasing infiltration rates. It was concluded that PAM has the potential to facilitate irrigation with high sodium wastewater.

Aly and Letey (1990) investigated the effectiveness of an anionic PAM (40J) and cationic guar (T-4141) in increasing aggregate stability and flocculation of sandy loam and sandy clay loam soils. Both PAM products were seen to increase flocculation over the control for soils with sodium adsorption ratios between 1 and 5. However only the PAM (40J) produced a measurable increase in flocculation in soil with SAR values of 15. The PAM product was also more effective at lower concentrations than the guar. They concluded that the effects of polymers on one soil property such as flocculation could not be extrapolated to the effects on another soil property such as aggregate stability or rupture stress. Aly and Letey (1989) also showed that PAM ameliorated soil hardness with water of EC 0.05 and 0.7 dS /m.

Malik *et al.* (1991), proposed that soil cracks could be used as drainage pathways if these cracks could be stabilised with PAM. Samples from a montmorillionitic soil were studied that had exchangeable sodium (ESP) of 8 and 25. Soil columns were wetted and dried to create cracks then ponded with anionic PAM solutions of 0,25,75 and 200 mg/L and allowed to drain and dry. In the cracked soils, increasing the amount of PAM added to the soil significantly increased hydraulic conductivity and salt removal. Where the PAM solution was applied directly onto the soil without creating cracks, there was no increase in hydraulic conductivity on the ESP=8 soil and only a small increase on the ESP=25 soil. Zahow and Amrheim (1992) studied the impact of PAM and gypsum on sodic soils. It was reported that PAM significantly increased hydraulic conductivity on soils with ESP values<15. When PAM and gypsum were used together hydraulic conductivity increased from 0.0 to 0.28 mm h -1 in a soil with an ESP of 32. Where gypsum was used alone hydraulic conductivity increased to only 0.063 mm/h.

Levey *et al.* (1995) added small amounts of anionic PAM to montmorillonitic soils with exchangeable sodium percentages greater than 12. Levy (1995) studied the impact that PAM had on runoff and erosion from sodic soils. In both soils studied PAM was seen to control runoff at low ESP (<4) but was inefficient at high ESP levels. However PAM applications to the irrigation water reduced soil erosion in moderate and high ESP soils. The addition of PAM at low rates can have a significant impact on water viscosity. It is possible that the reduction in erosion is due to the increased viscosity of the water slowing water movement across the soil surface.

While noting that soils have many different properties it is worth noting the potential that PAM may play an important role in reducing the impact that moderately saline water has on irrigated crops.

Impact of PAM on plant and soil nutrient levels

The application of PAM to soil has been shown to have an impact on plant and soil nutrient levels. Leaching of nutrients through the soil profile can contribute to ground water contamination and runoff from furrows can lead to nutrient losses from paddocks.

Wallace *et al.* (1986) grew wheat and tomatoes in soils containing amounts of anionic polymers than would be in excess of those required for soil stabilisation. The 1% rate increased the vegetative growth rate over the controls. The anionic polymer decreased the accumulation of phosphate and silicon in both wheat and tomatoes and decreased manganese and boron in wheat only. Applying 5% polymer was seen to depress accumulation of some of the macroelement cations.

Assessment of furrow runoff reveals water containing organic matter, sediments and nutrients. The addition of PAM with the water was seen to markedly reduce furrow runoff losses of sediment, orthophosphate, total phosphorus and chemical oxygen demand. The use of PAM did not appear to influence nitrate runoff Lentz *et al.* (1998a). PAM applied at 10mg/L during the furrow advance had 5-7 lower phosphate loads than the control areas (Lentz *et al.* 1998b).

Applications of polymers to soil have been observed to affect the nitrogen surface area of soil. Willams *et al.* (1966) used polyvinyl alcohol to change surface area and pore distribution of a clay soil. The amount of this polymer absorbed by aggregated material was less than the maximum absorbed by a dispersed soil. The data shows significant differences in nitrogen absorbed between controls and polymer treated soils at differing partial pressures. The addition of polymer revealed reduced absorption of nitrogen onto particles in montmorillonite soil.

Water absorbent PAM gels have been observed not only absorb water but reduce leaching losses of nitrogen in soilless medium (Bres and Watson 1993). PAM (HydroSource and Agri-gel) were incorporated into the growing medium at 1,2 and 3 g/L with 88g of ammonium nitrate. Water retention by the growth medium increased linearly with gel application. Nitrate N and ammonium N was higher when 3 g/L of PAM was added to the growth media. Total foliar nitrogen concentration in the tomato leaves was significantly higher in the HydroSource PAM than in either the control or Agri-gel treatments.

PAM has been used in coating urea (Abraham *et al.* 1995). N,N' methylene bisacrylamide crosslinked polyacrylamide was coated onto urea. The coated urea was found to have a greater slow release characteristic than when uncoated. There were differences in release of urea depending upon the PAM used in coating. In nutrient application the use of PAM treated fertiliser may be useful in reducing leaching losses and groundwater recharge.

It is worth noting that not all published research indicates that PAM is beneficial in all situations. Vlach (undated) investigated various water absorbing polymers in bentgrass golf greens. Results from this work indicated some PAM inhibited root development, and that starch polymers were more effective than PAM polymers. It is worth noting that in this paper polymers were seen to enhance tissue concentrations of nitrogen. This effect can be explained by the use of PAM increasing water holding ability of the root zone and it is therefore not unreasonable to suggest reductions in leaching losses. Inhibition of root development may be a consequence of excessive water being held in the root zone following an application of PAM.

This highlights the potential of PAM for use in the fertiliser industry in reducing leaching of nitrates and increasing availability and uptake by the plant.

Role of PAM on seedling survival and emergence

Maintaining moisture around the rootzone should theoretically increase a germinating plant's chances of survival. Lehrsch (1996) investigated the effects of PAM on sugar beet emergence. PAM was sprayed onto the soil which was later irrigated in with a lateral spread irrigator. The PAM tended to act as a soil stabiliser. PAM applications did not increase sugar beet emergence at varying sprinkler droplet energies. Seedling emergence was greatly increased by lowering the energy of the water droplet.

Huttermann *et al* (1999) used water absorbent PAM on sandy soils when planting pine seedlings. PAM was added to the soils at rates ranging from 0.4% to 4.0%. The water content of the soil was seen to increase with increasing concentrations of PAM. The highest concentration altered the soil water holding ability from that of a sand to a loam / silty clay. During drought conditions, treated seedlings exhibited pronounced growth of shoots and roots which were three fold higher than that of the controls. In drought prone Australia the use of water absorbent PAM could greatly increase the success of tree planting operations. Where growers are planting trees, the use of PAM could lead to quicker establishment and earlier returns on investments. Again the research data is scant and highlights the need for ongoing research into soil and water relationships and how these can be modified.

The influence of polyacrylamides on microorganisms

By altering flow, infiltration and runoff from irrigated paddocks with PAM it is not unreasonable to assume that soil biology will also be influenced. Sojka and Entry (1999) noted that PAM treated water accumulated algal tufts at the end of the furrows whereas untreated furrows did not. This observation led these workers to speculate that PAM might be used to intentionally sequester microorganisms from water flowing down furrows. Active fungi were also reduced in tailwater. The conclusion from the work was that applications of PAM reduced outflows of all classes of microorganisms observed. Microbial numbers generally increased along the furrow length. However the microbial numbers were less with PAM treated waters as the distance from the furrow outlet increased.

Intact cells of *Desulfovibrio desulfricans* were immobilised in a PAM gel. They were used to remove uranium and molybdenum from water by enzymatically mediated reduction reactions in column reactors (Tucker *et al*, 1998). The results indicated that the use of this technique was a practical way to remove these contaminants from solution in a continuous flow reactor. The combination of bacterial species and PAM make an interesting combination in controlling pollutants in waste water systems.

Shoemake-Kaye *et al.* (1998b) revealed that in PAM treated areas numbers of culturable heterotrophs were significantly elevated. This observation was recorded in potatoes but not dry beans. In the soils planted to potatoes, total soil nitrogen levels were significantly higher in PAM treated soils. Nitrate N and Ammonium N levels ranged from 36.7+/- 2.2 (Nitrate N) and 1.3+/-0.3 (Ammonium N) mg/kg in treated soils, versus 10.7+/- and 0.5+/- mg/kg for the same nitrogen form in untreated soils. The effect of PAM on inorganic nitrogen levels from this work appears to be very site specific. However inputs of nitrogen onto a potato crop would be higher than for dry beans and this additional nitrogen may bind to PAM in the soil and become a subsequent food source for soil microorganisms. However Shoemake-Kaye *et al.* (1998) points out that PAM is able to support bacterial growth as the sole nitrogen source in enrichment cultures.

The aim of this trial is to investigate the role of PAM in drip and centre pivot irrigation systems, and the ability to have an impact on soil hydraulic conductivity, wettability and water retention. In Australia, which suffers from variability of flows in its rivers and severe droughts, PAM may have great potential in future irrigation scheduling practices.

Entry et al (2000) investigated the role of polyacryalmides for biocontrol of bacterial diseases on potatoes. The use of wood chip polyacrylamides could be seen to reduce Verticillium dahliae on potatoes. The wood chip polyacryamide was placed around the host plant roots altering the environment in favour of introduced biocontrol microorganisms, thereby reducing Verticillium dahliae infection of potato.

PAM has been shown to alter water infiltration rates. As a result there have been significant changes to soil nutrient levels, changes to microbial populations and impacts on plant growth and development. In Australia the emerging crisis in soil water management in the Murray Darling Basin makes the investigation into PAM applications worthy of more detailed attention.

Degradation of Polyacrylamides and Plant Uptake

The environmental fate of polyacrylamides is a major concern to both manufacturers and consumers so that the use of the product does not cause adverse effects to the environment.

Seybold (1994) in her review of polyacrylamides and environmental fate notes that ‘PAM has been shown to be non-toxic to humans, animals, fish and plants, the only concern has been the toxicity of the residual monomer (acrylamide) content, which is a known neurotoxin to humans.’ The residual monomer is biodegradable and does not accumulate in soils. As the major source of the acrlyamide is from acrylamide products the USA FDA regulates the residual monomer content of PAM used in food contact products. If the acrylamide content is kept to a minimum, PAM does not pose any environmental threat, and thus can be used effectively as a soil conditioner.

Kunichika and Shinichi (1995) isolated two PAM degrading bacteria from soil samples. These were Enterobacter agglomerans and Azomonas macrocytogenes. Both strains grew on a medium of composed of 10mg/ml polyacrylamide as the sole source of carbon and nitrogen. After 27 hours of cultivation about 20% of the total carbon in the initial medium had been consumed.

Shoemake et al (1998) documents how linear PAM increased the number of culturable heterotrophs on soils sown to potatoes. Shoemake summised that the constituents of PAM, acryalamide andacryalic acid supported bacterial growth as the sole carbon source. The research indicated that PAM may ultimately converted into long chain polyacrylate, which may be further degraded by physical and biological mechanisms or be incorporated into organic matter.

Seybold (1993) acknowledges that PAM if used correctly, does not pose any threat to higher organisms. The only concern is the residual monomer, which is a known neurotoxin to humans. PAM is resistant to microbial degradation. However in aqueous solutions PAM provides a substrate for mould if nutrients are present. Seybold (1994) reports that PAM can be broken down by cultivation, sunlight and the mechanical breakage of the monomer chain. Levy *et al.* (1992) suggested that the wetting and drying cycle that occurs in soils may cause degradation and reduced efficiency of the PAM. In the South Australian mallee, drying and occasional wetting cycles would dominate the rural landscape. How this would affect the longevity of the PAM in soil solution is unknown at this stage. However, the ability of PAM to increase soil nitrogen levels may indicate enough structural change to the monomer through attachment of nitrate and ammonium ions to facilitate microbial breakdown in soils.

Much of the literature acknowledges the toxicity of the residual acrylamide monomer (AMD) and the safety of the polacrylamide molecule. Bologna et al (1999) undertook studies to determine the content of AMD in field crops grown under PAM treatments. Crops studied were corn, potatoes, sugar beets and beans. Analysis of these crops by chromatography showed less than 10ppb AMD. It was stated that it appears that AMD is not stable when it comes into contact with plant tissue. Beans blended with 100ppb AMD for 10 minutes yielded a recovery of only 22%. For the bean sample soaked with 500ppb AMD solution for 18 hours, the recovery was 7%. From this paper results indicated that AMD was more stable in potatoes than the other crops studied. In these studies the speed at which AMD disappeared it is suggested that it is unlikely to be present at any level in plant tissue. Results provided by Castle et al (1991) suggest that the bioaccumulation of MD in plant tissues is highly unlikely. The half-life of AMD in aerobic soils is in the order of several days at 20 C (Bologna, 1999). In the hot Australian summer the half life of the AMD molecule may be well much shorter than this.

Conclusion

Polyacryalmides are extensively used in the treatment of potable water supplies, controlling soil erosion. Significant research indicates the both the polyacryalmide molecule and the AMD monomer are broken down in soils, by physical, biological and chemical means. Researchers are also in consensus that while PAM is a relatively stable molecule it will undergo some chemical reactions in the environment, it will not regenerate the AMD monomer (Buchnolz 1992).

The PAM molecule is considered too large to be transported across biological membranes. Thermal depolymerisation does not occur rather that other reactions take place upon the heating of PAM (loss of ammonia from the amide group). PAM is also hydrolysed at high pH, the presence of biological compounds, microorganisms and light (UV).

References

Aase J.K.,Bjourneborg D.L.,Sojka R.E. (1986) Sprinkler Irrigation Runoff and Erosion Control with Polyacrylamide – Laboratory Tests
Soil Sci. Soc. Amer.J. 62, 1681-1686

Abraham J.,Rajasekharan Pillai V.N. (1990). N,N' – methylene bisacrylamide crosslinked polyacrylamide for controlled release urea fertiliser formulations.
Comm. Soil Sci. Plant Anal. 26, 3231-3241

Aly S., Letey J. (1990). Physical properties of sodium treated soil as affected by two polymers.
Soil Sci. Soc. Amer. J. 54, 504-510

Aly S., Letey J.(1989). The effect of two polymers and water qualities on dry cohesive strength of three soils.
Soil Sci. Soc. Amer. J. 53, 255-259

Azzam, R. (1980). Agricultural polymers, polyacrylamide preparation, application and prospects in soil conditioning.
Comm. Soil Sci. Plant Anal. 11, 767-834

Becker H. (1977). Stopping Erosion with PAM and Gypsum
Agricultural Research 45, no.9, 18-21

Bologna L.S.,Andrwaes F.F., Barvenik F.W. (1999): Analysis of residual acrylamide in field crops
J. Chrom. Sci. 37, 240-244

Bres W.,Weston L.A.(1993). Influence of gel additives on nitrate, ammonium and water retention and tomato growth in a soilless medium.
HortScience 28, 1005-1007

Burgess H.D. (1998). Formulation of Microbial Biopesticides.
Kluwer Academic Publishers London

Buchnolz F.L. (1992): Polacrylamide and polyacrylic acids.
Ulmans Encyclopedia of Polymer Science and Engineering, B.S Elvers, S. Hawkins and Schultz, Eds. Wiley VCH, Weinheim, Germany, 1992, A21, 143-156

Carter, D.L,Brockway C.E.,Tanji K.K. (1993). Controlling erosion and sediment loss from furrow irrigated cropland.
J. Irrig. and Drainage Engineering 119, 975-987

Chamberlain P. (1988). Polymers as soil conditioners.
Chemistry in Britain February, 144-146

CastleL.,Compos M.J., Gilbert J. (1991): Determination of acryalmide monomer in hydroponically grown tomato fruits.
J. Sci. Food Agric. Chem. 54, 549-555
Entr y J.A, Strasbaugh C.A., Sojka R.E. (2000). Wood chip Polyacrylamide Medium for Biocontrol Bacteria Decreases *Verticillium dahliae* Infection on Potato
Biocontrol Science and Technology 10, 677-686

Finch C.A. (1973). Polyvinyl Alcohol – Properties and Applications
John Wiley and Sons Ltd., 622pgs

Gardiner D., Shainberg I. (1996). Effects of PAM on infiltration of high sodium water.
Institute of Soils and Water, The Volcani Centre, PO Box 6, Bet Dagan Israel. 1996

Huttermann A.,Zommorodi M.,Reise K.(1999): Addition of hydrogels to soil for prolonging the survival of *Pinus halepensis* seedlings subjected to drought.
Soil Till. Res. 50, 295-304

Kunichika N., Shinichi K. (1995). Isolation of polyacrylamide degrdaig bacteria.
J. Fermentation and Bioengineering. 4, 418-420

Lentz R.D., Sojka R.E., Carter D.L.(1993). Influence of polymer charge type and density of polyacrylamide ameliorated irrigated furrow erosion.
USSA-ARS Soil and Water Management Research

Lentz R.D.,Sojka R.E.,Robbins C.W. (1998a) Reducing soil and nutrient losses from furrow irrigated fields with polymer application.
Advances GeoEcol. 31, 1233-1238

Lentz R.D.,Sojka R.E.,Robbins C.W. (1998b). Reducing phosphorus losses from surface irrigated fields: Emerging polymer technology.
J. Environ. Qual. 27,305-312

Levy G.J., Ben-Hur M.,Agassi M.(1991). The effect of polyacrylamide on runoff, erosion, and cotton yield from fields irrigated with moving sprinkler systems. Irrig. Sci. 12, 55 – 60

Levy G.J.,Levin J.,Shainberg I. (1995). Polymer effects on runoff and soil erosion from sodic soils. Irrig. Sci. 16, 9-14

Levy G.J.,Levin J.,Gai M.,Ben-Hur M.,Shainberg I. (1992). Polymer Effects on Infiltration and Soil Erosion during consecutive Simulated Sprinkler Irrigations. J. Soil Sci. Soc. Amer. 56, 902-907

Malik M., Amrhein C., Letey J. (1991).Polyacrylamide to improve water flow and salt removal in a high shrink swell soil.
J. Soil Sci. Soc. Amer. 55, 1664-1667

Orts W.J., Sojka R.E., Glenn G.M. (2000). Bioploymer additives to reduce erosion induced soil losses during irrigation. Ind. Crops Prod. 11, 19-29

Pritchard J.G. (1970). Poly (vinyl alcohol) – Basic properties and uses.
Gordon and Breach Science Publishers Ltd. 139pgs

Ross,C.W., Sojka, R.E.,Lentz R.D. (1996) Polyacrylamide as a tool for controlling sediment runoff and improving infiltration under furrow irrigation. Proc. Australian New Zealand Nat. Soils Conf. Volume 2 Oral Papers 229-230

Seybold C. (1993) Polyacrylamide : Soil Conditioning and Environmental Fate.
Comm. Soil Sci. Plant Anal. 25, 2171-2185

Shoemake-Kay J.L.,Watwood M.E,.Lentz R.D.,Sojka R.E.(1998) Polyacrylamide as an organic nitrogen source for soil microorganisms with potential effects on inorganic soil nitrogen in agricultural soil.
Soil Biol. Biochem. 30, 1045-1052

Shoemake-Kay J.L.,Watwood M.E,.Lentz R.D.,Sojka R.E. (1998) Polyacrylamide as a substrate for microbial amidase in culture and soil. Soil Biol. Biochem., 30,1647-1654

Sojka R.E., Entry J.A. (1999). Polyacrylamide applications to soil reduces the movement of microorganisms in water.
Proc. International Irrigation Show, 93-99

Sojka,R.E., Lentz,R.D. (1996). A PAM Primer : A brief history of PAM and PAM related issues.
Symp. Managing Irrigation Induced Erosion and Infiltration with Polyacrylamide May 6-8 , Twin Falls ID, University of Idaho, Misc. Pub. 101/96, 11-20

Sojka,R.E., Lentz,R.D., Westermann D.T. (1998). Water and erosion management with multiple applications of polyacrylamide in furrow irrigation. Soil Sci. Soc. Amer. J. 62, 172-1680

Sojka R.E., Surapaneni A. (2000). Potential use of PAM in Australian agriculture to improve off and on site environmental impacts and infiltration management. LWRRDC Project Number UNE 39 Polyacrylamides in Agriculture. Final report June 2000 (unpublished)

Stern R., Van Der Merwe A.J., Laker M.C.,Shainberg I.(1992). Effect of soil surface treatments on runoff and wheat yields under irrigation.
Agronomy Journal Volume 84, 114-119

Stumm.W.(1992). Chemistry of the Solid-Water Interface. John Wiley @ Sons, Inc. 427pgs

Trout T.J., Sojka R.E., Lentz R.D. (1995). Polyacrylamide effect on furrow erosion and infiltration. Amer. Soc. Agricultural Engin. 38, 761-765

Tucker M.D.,Barton L.L.,Thomson B.M. (1998). Removal of U and Mo from water by immobilised *Desulfovibrio desulfricans* in column reactors. Biotech. Bioeng., 60, 88-96

WallaceA.,Wallace G.A.,Abouzamzam A.M.(1986). Effects of excess levels of a polymer as a soil conditioner on yields and mineral nutrition of plants. Soil Sci. 141, 377-380

Wilson, AD, Crisp, S. (1975) Rigid highly carboxylated ionic polymers. In Ionic Polymers. L. Holiday (Ed.). Chapman and Hall, New York

Young, R.J. (1981). Introduction to polymers. Chapman and Hall, New York.

Zahow M.F.,Amrhein C.(1992). Reclamation of a saline sodic soil using synthetic polymers and gypsum. Soil Sci. Soc. Amer. J. 56, 1257-1260 (1992)

Additional Reading

Ciba Specialty Products (1996). Theory behind soilfix application
Soilfix Training Course September

Green V.S.,Stott D.E.: Effect of different polyacrylamide configurations on soil crust formations. 2001
http://pasture.ecn.purdue.edu

Lehrsch G.A.,Kincaid D.C.,Lentz R.D. (1996) PAM effects on sugarbeet emergence.
USDA-ARS, Soil and Water Management Research Unit
http://www.nalusda.gov/ttic/tektran/data

Prior A.,: Water absorbing polymers have been shown to improve the yield in processing tomatoes.
hhtp://www.kern:com/~hydrosrc/pretty.html

Sojka,R.E., Lentz,R.D. (1994). Polyacrylaimde (PAM) - A new weapon in the fight against irrigation induced erosion. USDA - ARS Northwest Irrigation and Soils Research Lab Station Note 1994

Sojka,R.E., Lentz,R.D. ,BjorneborgD.L., EntryJ.A., Morishita D., RossC.R., Trout T.J.(1999). Polyacrylamide (PAM)-A one million acre progress report.
Proc. Inter. Irrig. Show 7-9 November 1999, Orlando Florida

Sojka,R.E.,Lentz,R.D. (1993). Improving water quality of return flows in furrow irrigated systems using polymer amended inflows.

Agricultural Research to Protect Water Quality.
Proceedings of the Conference February 21-24 1993
Minneapolis, Minnesota USA, 395-396

Sousa P., Osterli P.(1998) PAM Field Trial
UC Cooperative Extension, Stanislaus County (unpublished)

Schiller C. (1997). Increasing irrigation efficiency and reducing pesticide runoff with polyacrylamides. Ozchem Pty Ltd & E. Edmunds, Cytec Australia Pty Ltd

Vallant J.,: The use of PAMs to reduce erosion and increase yields of furrow irrigated tomatoes and Jalapeno peppers in the Arkansas River Valley of Colorado.
.hhtp://www.colostate.edu/Depts/CoopExr/SEA/hptiar97.la.html

Vlach T.R.,: Creeping bentgrass response to water absorbing polymers in simulated golf greens.
hhtp://www.kern:com/~hydrsrc/creeping.html

Williams,K.R.. (1998) Polymer Analysis,
http://www.mines.edu/Academic/chemistry/faculty/kw_hp5.html